ELECTRIC AND MAGNETIC FIELDS

Electric Fields. The various radiations in the electromagnetic spectrum affect living organisms quite differently. The energy is proportional to the frequency, and is sufficient to produce ionization at the frequency of X-rays, and the visible portions of the spectrum. The energy is much too low to produce ionization in the lower radiofrequency megacycle and microwave ranges. At these frequencies the primary effect observed is heating attributed to the resistance of the electromagnetic wave passing through a "lossy" dielectric. Radiofrequency absorbing material converts the absorbed energy into heat. There is evidence for nonthermal effects of radio waves which are as yet undefined. It is possible, for example, to achieve gross killing and mutation effects with equipment which pulses the radio waves so that no measurable temperature change is detected. These experiments are especially interesting because the energy is applied for total exposures of seconds or minutes at low power.

There is a considerable literature on biological effects of radiofrequency energy, but it is difficult to reproduce experiments in several laboratories because of the variables associated with the equipment and experimental conditions. Radiofrequency equip-

ment must be designed for a particular application, and is generally not available as an off-the-shelf commodity. There is good evidence that killing of microorganisms is frequency specific within a narrow band. Thus conditions shown to kill all Salmonella senftenberg in cocoanut meat do not injure bacterial spores.

Ark and Parry (172) reviewed the pre-1940 literature on biological effects of high frequency oscillating fields. They called attention to the specific frequency requirements for killing various bacteria and fungi. Erwinia carotovora suspended in an electrolyte was killed rapidly at 10.4 meters but was not killed in the dry state at this wavelength. Lethal effects of a wavelength of 5.6 meters against several fungi began when the temperature reached 30-40 C. This temperature range was not lethal in the absence of a field.

Nyrop (173) summarized the results of a series of investigations in which the specific effects of electric field with minimal heating were explored. These experiments were at 20 mc. Bacteria and virus were killed in exposures of 10 sec or less. Unfortunately, Nyrop died without preparing detailed reports, and none of his experiments will be published other than the single citation.

Although penetration and scattering is a function of each

frequency, Kosikowsky, Herrington, and Dahlberg (174) raised the temperature of a 1.3 lb block of cheese to 117-155 F (47-68 C) within 1.5-2.7 min by means of an oscillator operating at 150 mc at a possible power output of 750 w. The bacterial count was greatly reduced by this treatment.

Jacobs, Thornley, and Maurice (175) recognized the variables associated with any application of megacycle range rf as a bactericidal agent, but did not exclude the possibility that marked effects might be obtained at highly critical frequencies. These workers considered the bacterial cell as a complex of molecules bearing unequally distributed electrical charges. A rapidly alternating electric field of high potential gradient might disrupt an essential molecule at a weak bond. Limitations imposed by the frequencies and power in their experiments, the electrode arrangement, and failure to induce high mortalities, led this group to conclude that it is unlikely that this technique will have any practical application in sterilization other than providing uniform heating.

King (177) showed that microwave heating at 2450 mc followed by ionizing irradiation inactivated proteolytic enzymes in meat, yielding a product of good quality. Radiation sterilization processes ordinarily require considerably higher doses for enzyme

inactivation than are required for microbial inactivation. The food product may then be organoleptically unacceptable.

Grecz, Walker, and Anellis (179) found that microwave heating at 2450 mc in a constant temperature device was consistently much more lethal to Clostridium sporogenes PA 3679 spores in buffer at 85, 95, and 100 C than conventional heating. Microwave treatment of dry spores did not influence viability. A dose of 0.4 Mrad gamma rays significantly decreased spore resistance to heat and to a greater degree to microwave heat. Radiation resistance was only slightly affected if microwave or conventional heat preceded the irradiation.

Heinmets and Herschman (178) indicated that it is difficult to obtain uniform fields in experiments with combined magnetic and electric fields. They postulated that combined fields would not necessarily kill cells directly, but would cause abnormal cell growth which might lead to cell death. The greatest activity of combined fields would occur when electric and magnetic fields of a travelling wave are in phase and perpendicular to each other. Dielectric heating of the medium or the object occurs. These views relate to particles in liquid.

The 20-30 mc range has been determined by John Heller and his associates at the New England Institute for Medical Research

Ridgefield, Connecticut to be bactericidal. Pulsed rf experiments performed at Ridgefield by personnel of the Research Laboratories, Wilmot Castle Company, showed that bacteria were killed on a variety of objects but none of the experimental conditions accomplished sterilization. The power requirements for rf studies are quite low, but a complex interaction of several variables presents the greatest barrier limiting an orderly experimental program. These variables include frequency, field strength (voltage), pulse width (if not continuous wave), repetition rate, and total time in the field. It is likely that a system in which rf and moderate heat were applied simultaneously would be most effective since slight heating seems to enhance the rf effect. A continuous wave process rather than a pulsed system might be useful if heating can be tolerated.

Heller has demonstrated (unpublished) that rf sterilized semiconductors which had microbial contamination without affecting performance of the component. In any extension of this work, however, it will be necessary to manipulate the exposure conditions to determine the appropriate system which will avoid any possibility of damage due to excessive rf energy. Perhaps the primary limitation of rf in any spacecraft application would be the metallic elements in electronic devices. Metals provide total shielding to rf so that the field becomes distorted and the metal heats up. Most

plastics are transparent to rf and would be good candidates for an rf study. It should be possible to sterilize certain spacecraft components and subsystems nonthermally with rf prior to final assembly. Transistors and diodes would probably be less reliable after an rf treatment at high field strength. In an extension of this concept, it may be possible to sterilize the spacecraft exterior prior to launch or after returning from an extraterrestrial mission by imposing a symmetrical field around the spacecraft.

Magnetic Fields. Magnetic fields do not appear to be useful in sterilization. Growth inhibition has been noted in cultures maintained in magnetic fields, but several species have been unaffected by conditions which influence the growth rate of other organisms. Exposures of long duration to strong fields seem necessary to demonstrate significant inhibition. All reports cited concern cultures in suspension. The response of organisms in anhydrous environments or under conditions in which the cells are immobilized does not appear to have been investigated. It is probable that inductive effects of magnetic fields would adversely affect diodes and other components.

Halpern and Greene (61) did not find any magnetic field effect on HeLa cells. Beischer (180) employed a much stronger field (140,000 Oe) but could not detect mutants in Neurospora

crassa conidia in a 2-hr exposure. The light emission from Photobacterium fischeri was not changed after 1-hr in this field.

Gerencser, Barnothy and Barnothy (181) studied bacterial growth in magnetic fields. Serratia marcescens cultures in a field averaging 15,000 Oe had the same growth rate and cell numbers as control cultures for up to 6 hr. The magnet cultures then increased at a slower rate for several hours but then increased at a greater rate than the control so that after 10 hr the magnet culture surpassed the control.. Staphylococcus aureus magnet cultures had an early period of more rapid growth than the control. Growth inhibition then occurred for several hours, but magnet and control cultures were equivalent at the 9th hr.

Hedrick (182) also observed growth inhibition in magnetic field cultures. Staphylococcus aureus exposed to a 14,000 Oe homogeneous field and control cultures were similar for 15 hr. Inhibition of growth in the field was noted at the 16th hr and continued until the end of the 24 hr exposure when the plate count was about one-fifth that of the control. Inhibition did not occur if the homogeneous field was interrupted hourly for 3 sec. Neither Sarcina lutea nor Escherichia coli showed cell population differences in similar experiments.